International Journal of Electrical and Electronics
Engineering Research (IJEEER)
ISSN(P): 2250-155X; ISSN(E): 2278-943X
Vol. 5, Issue 5, Oct 2015, 93-106


# DIRECT & INDIRECT CURRENT CONTROL OF UPQC FOR ENHANCING POWER QUALITY

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## ABSTRACT

The complexity of power systems nowadays is increasing at a rapid rate because of usage of complex loads by different types of consumers, so there is a need for the utility to deliver the loads, meeting all the power quality issues. The major power quality issues which cause loss to the consumers (mostly production industries) are harmonic distortion, voltage sag and voltage swells. The need for developing dynamic & adjustable solution to mitigate the power quality problems has gained a great attention in the present research areas of power systems, as the harmonic content in power system is increasing severely. One such solution lies in the use of FACTS controllers, which have acquired significance in recent times. Of all the FACTS controller, Unified Power Quality Conditioner (UPQC) is a controller that can tackle both current and voltage related issues simultaneously. In this paper design of UPQC is done, with a combination of series, shunt active filters and RL passive filters, which is one of the solution for minimizing the effect of voltage sag at load terminals or at Point of Common Coupling (PCC), which also restricts the current harmonics at the load to enter into the utilities and hence improving the power factor at the load. The modeling of UPQC controller is done using MATLAB-SIMULINK.

**KEYWORDS:** Power Quality, Series & Shunt active filters, Voltage Sag, Shunt control, Series Control, Fuzzy, UPQC

## INTRODUCTION

With the development of power semiconductor and power electronics applications, power electronics related equipment are being used widely in several applications, which include thyristorised switching converters, industrial furnaces, rectifier circuits, variable controlled voltage sources etc,. The usage of personal computers, refrigerators, air conditioners and other utilities which adds complexity to the present system are widely used by almost all kinds of customers, as a result of this the power supply utilities and the end users are facing many intrications like the power quality and reliability issues. So there is a need to serve these complex loads by the power supply utilities considering its generating constraints.

With today’s sensitive equipment such as adjustable speed drives (ASDs) voltage sags to 90% of nominal may cause shutdown. The increased usage of complex loads like thyristor based switching converters, rectifier circuits, industrial furnaces etc., has increased the harmonic content at the terminals of both load & utility which has become a serious concern in power system [3]. These issues are solved up to a certain extent by using filtering circuits at specified locations in power systems. Generally these filtering circuits use passive elements like inductors (L) & capacitors (C) and hence called as passive filters, but these filters are designed for a particular variation of loads and not for random or sudden variations in loads. In practical applications these filters suffer from few drawbacks such as, resonance condition w.r.t

system impedance, problems related to tuning of filter parameters & aging because of continuous usage. To overcome these drawbacks the engineers/researchers has developed shunt active filters, which is connected parallel to the complex loads, delivering the harmonic currents needed by loads and hence acting as sources of current [4]. In this form the mains only need to supply the fundamental, avoiding contamination problems along the transmission lines. With an appropriated control strategy, it is also possible to correct power factor and unbalanced loads. However, the cost of these active filters is high, and they are difficult to implement in large scale. Additionally, they also present lower efficiency than shunt passive filters. Because of above mentioned reasons various methodologies or process of tuning these active filters were proposed for enhancing the effective utilization of active filters. One such methodology is the combination of shunt passive filters & series active filters for filtering the load current harmonics. In this solution the cost & overall system efficiency is optimized by designing the active filter only for a fraction of total load power [4].

## POWER QUALITY

Power quality is basically the issues related to qualitative delivery of power at the load terminals, meeting all the constraints, considering few power quality indices such as voltage sag, voltage swell, harmonics, THD etc. If a system fails to meet those constraints and quality indices, then it is said to have poor power quality. On the other hand if all the components of the power system meet those constraints & indices then the system is of good quality .

At the generating station utilities create a perfect sine The generating station utilities produce a pure sinusoidal wave which is free from noise, harmonic distortion & transients. This pure sinusoidal supply is then transmitted to the load at various levels of voltages through the transmission & distribution line/utilities which are prone to disturbances & failures like lightning, switching transients, harmonics, and component failures. These disturbances are sent back through the transmission & distribution utilities, disturbing the utility voltage and hence leading to reliability & Quality issues. So, the power quality in general can be treated as the deviation from the normal supply voltage, by distorting it. Power quality issues can be very high-speed events such as voltage impulses / transients, high frequency noise, wave shape faults, voltage swells and sags and total power loss. Power quality issues will affect each type of electrical equipment differently. They may cause equipment heating, measurement faults and scores of other similar problems.

### Solutions to Power Quality Problems

In general there are three ways to solve the problems of power quality and provide quality power customized to meet user’s requirement:

- System improvement.
- Use mitigation equipment based on power electronics.
- Improvement of equipment immunity.

Of these, the best way to handle power quality problems is to mitigate the effects of distorted voltage or current at the Point of Common Coupling. This solution restricts the harmonics from entering into distribution system and contaminating the system power as a whole. Thereby, the other loads connected to the system are provided with clean power [2]. Conventionally, passive filters have been used to mitigate the effect of power supply discrepancies, such as line current and voltage harmonics, and increase the load power factor the need for developing optimal solutions to minimize the power quality issues has gained a great attention in the present research areas of power systems, as the harmonic content in power system is increasing severely. One such solution lies in the use of *FACTS* controllers, which have

acquired significance in recent times [7].

## FACTS

FACTS devices are one of the important aspects of advanced power electronics which is playing a crucial role in power engineering. A variety of powerful semiconductor devices not only offer the advantage of high speed and reliability of switching but, more importantly, the opportunity offered by a variety of innovative circuit concepts based on these power devices enhance the value of electrical energy.

**FACTS Controller:** It is a static device which consists of higher power rating power handling device like; power SCR's, power diodes etc. which controls the parameters of AC transmission system to get the desired output.

### Basic Types of FACTS Controllers

**Series Compensator:** It is basically a capacitor, reactor etc., whose impedance value can be varied based on the extent of compensation required. In general this series compensator acts, by injecting a voltage in series to the line to be compensated.

**Shunt Compensator:** It is also similar to shunt compensator in which variable impedance, a variable source or combination of these two can be used for compensating the line. This shunt compensator acts, by injecting a current at the point where it is connected in the system. The current can also be injected by using variable impedance connected across the line and hence causing the current to vary.

**Combination of Series-shunt Controllers:** *It* is in general the combination of both shunt & series compensators which will be in coordination with one another or it can be simply a Unified Power Quality Conditioner with both shunt & series controllers. Since it is combination of series & shunt controllers, it combines both the actions by injecting current in line using the shunt compensator and by injecting voltage in series to line using series compensator [4]. As both the compensators are combined using a power link, there might be a exchange of real power between them which needed to be considered for effective compensation.

**Custom Power:** It is the concept where specific processes & facilities are supplied with consistent level of power quality for the effective performance of these processes/facilities by using thyristorised/power electronic converters in power distribution utilities..

**Custom Power Controller:** It is the power electronic controller which is employed for improving the power quality in distribution system by interrupting the current, regulating the voltage or both.

The custom power controllers are in general divided into two classes:

- One which compensates the harmonic content/reactive power and,
- Other which mitigates the voltage interruption/voltage sag.

### Harmonic Content/Reactive Power Compensation Devices

- Static VAR Compensators (SVC), which uses variable impedance i.e, thyristor controlled capacitors & inductors.
- Static Synchronous Compensator, which use the voltage source converter connected across the line. STATCOM; D-STATCOM [2].

**Voltage Sag/Interruption Mitigating Devices**

- Static series Compensator (SSC), using IGBT's as switching devices [5]
- Static Voltage Regulator (SVR), is basically a tap changing transformer in which the tapings are controlled using thyristorised switches.
- Static Transfer Switch (STS) which basically transfers the load using thyristorised switches.
- A D-STATCOM with energy storage capability.

Of the above mentioned devices/controllers some are used to handle the issues related to current and some are for voltage issues, these devices actually handle the real values of current and voltage form the system. So there is a demand for a device/controller which handles both the real values of current and voltage, these has lead to development of a controller using series active and shunt active filters which handles only a part of real load, thereby minimizing the complexity & cost of the controller and improving the efficiency of the system.

## UNIFIED POWER QUALITY CONDITIONER

In general the block diagram of a UPQC consists of a bidirectional converter connected to a DC link using back to back connected IGBT controller circuits, PWM controller to control voltage & current and a filtering circuit using passive components like R &L connected at PCC parallel to load, the load used here is a non linear load, which is an RL load fed by diode bridge rectifier [3][9]. In the block diagram two inverters are used to compensate the voltage and current, the one which is used for compensating voltage is connected in series with the load and the one which is used for compensating current is connected in parallel with the load [3].

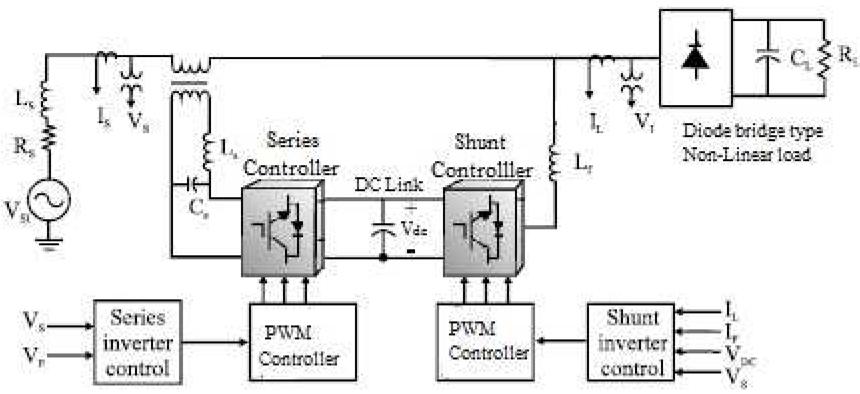


**Figure 1: Basic block diagram of UPQC**

## CONTROL STRATEGY FOR GENERATING THE REFERENCE CURRENTS

- **Shunt Control**

The shunt control technique is used to charge dc link capacitor to required value for driving the inverters and to compensate the harmonic currents by generating reference currents. [4].

**Charging of Capacitor:** In order to maintain constant voltage at the dc link, a closed loop control is established in which the voltage across the capacitor is measured at regular intervals and continuously compared with the reference vlaues. The measured dc link voltage, $V_{dc}$ is compared with its reference value $V_{dc}^{\circ}$. The error signal is fed to a Fuzzy controller the results of which are compared with that of a PI controller. The output of the Fuzzy controller is denoted as

$i_{sp}$ . Thus, the dc bus voltage of the UPQC is maintained to have a proper current control [9].

**Computation of Control Quantities of Shunt Inverter**

- **Direct Current Control Method**

From the obtained three phase values, the supply voltage can be written as:

$$v_{sm} = \sqrt{\left[\frac{2}{3}\left(v_{sa}^2 + v_{sb}^2 + v_{sc}^2\right)\right]} \quad (1)$$

The expression for three phase unit current vector is given by:

$$u_{sa} = \frac{v_{sa}}{v_{sm}}\,;\, u_{sb} = \frac{v_{sb}}{v_{sm}}\,;\, u_{sc} = \frac{v_{sc}}{v_{sm}} \quad (2)$$

The three phase reference supply currents are obtained by multiplying the three phase unit current vectors with the supply current ($i_{sp}$) magnitude:

$$i_{sa}^{\circ} = i_{sp} \times u_{sa}\,;\, i_{sb}^{\circ} = i_{sp} \times u_{sb}\,;\, i_{sc}^{\circ} = i_{sp} \times u_{sc} \quad (3)$$

The three phase load currents are substracted from three phase reference supply currents to get the expression for reference currents:

$$i_{sha}^{\circ} = i_{sa}^{\circ} - i_{la}\,;\, i_{shb}^{\circ} = i_{sb}^{\circ} - i_{lb}\,;\, i_{shc}^{\circ} = i_{sc}^{\circ} - i_{lc} \quad (4)$$

In the above block diagram shown, PWM controllers are used to control the voltage & current, the PWM current control develops switching pulses for the shunt inverter which supplies currents demanded by the load, by comparing the reference currents $i_{sha}^{\circ}$, $i_{shb}^{\circ}$ & $i_{shc}^{\circ}$ with the actual compensating currents (shunt currents) $i_{sha}$, $i_{shb}$ & $i_{shc}$.

- **Indirect Current Control method:** As in case of direct current control the reference phase current $i_{sa}^{\circ}$, $i_{sb}^{\circ}$ & $i_{sc}^{\circ}$ are generated and are compared with the actual measured supply currents $i_{sa}$, $i_{sb}$ & $i_{sc}$, the error signal which got generated are converted as switching pulses with the help of PWM shunt converter and are used for switching of devices in shunt inverter.
- **Series Control**

The series inverter compensates the supply voltage disturbances like voltage sag & swell by adding a voltage source between the load and supply and hence operating in current control mode. The series inverter in closed loop control substracts the three phase load voltage $V_{la}$, $V_{lb}$ & $V_{lc}$ from three phase supply voltage $V_{sa}$, $V_{sb}$ & $V_{sc}$ which is compared with reference supply voltage resulting in reference voltages $V_{la}^{\circ}$, $V_{lb}^{\circ}$ & $V_{lc}^{\circ}$. From these reference phase voltages, reference currents $i_{sea}^{\circ}$, $i_{seb}^{\circ}$ & $i_{sec}^{\circ}$ are gnerated and are fed to the PWM current controller along with the actual/measured values $i_{sea}$, $i_{seb}$ & $i_{sec}$. This PWM current controller ensures that the disturbances in voltage i.e, voltage sag & swell are minimised by sending the appropriate gating signals to the series inverter and hence delivering a pure sinusoidal voltage to the load. Thus whenever there is a voltage sag/swell, the series inverter minimizes it by injecting a suitable voltage at the supply voltage. For the DC link, the series inverter acts as a load, which exhausts the energy of dc link when voltage sag occurs [6]. Thus the UPQC doesn't require any external storage equipment or additional diode bridge rectifier to supply voltage to DC link, unllike the Dynamic Voltage Restorer (DVR).

**Fuzzy Logic Controller for DC Link**

The fuzzy variable ranges used in the controlling of UPQC are:

- **Input**

a) Error

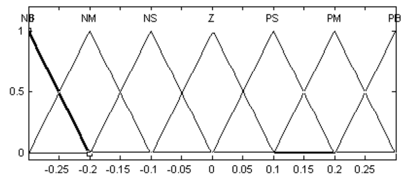


**Figure 2: Membership function for Input 1(Error)**

b) Change in Error

The range of change in error is -0.01 to 0.01.

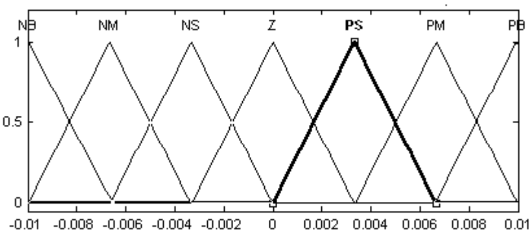


**Figure 3: Membership Function for Input 2(Change in Error)**

- **Output**

The output range is -0.3 to 0.3.

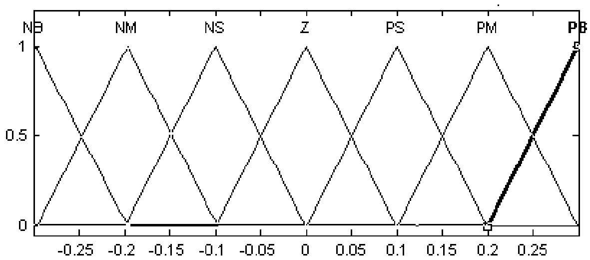


**Figure 4: Membership Function for Output**

The Fuzzy rules applied in the controller, are represented in the form of table.

**Table 1: Fuzzy Rule base for control of DC link**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ***Error*** | NB | Zero | NS | NM | NB | NB | NB | NB |
| | NM | PS | Zero | NS | NM | NM | NB | NB |
| | NS | PM | PS | Zero | NS | NS | NM | NB |
| | Zero | PM | PM | PS | Zero | NS | NM | NM |
| | PS | PB | PM | PS | PS | Zero | NS | NM |
| | PM | PB | PB | PM | PM | PS | Zero | NS |
| | PB | PB | PB | PB | PB | PM | PS | Zero |
| | | NB | NM | NS | Zero | PS | PM | PB |
| | ***Change in Error ($\Delta E$)*** | | | | | | | |

A PI controller whose gain constants are designed using conventional method is also used to control the DC link

voltage and is compared with respect to that of Fuzzy logic controller.

## SIMULATION AND RESULTS

### Shunt Control Simulation Diagrams

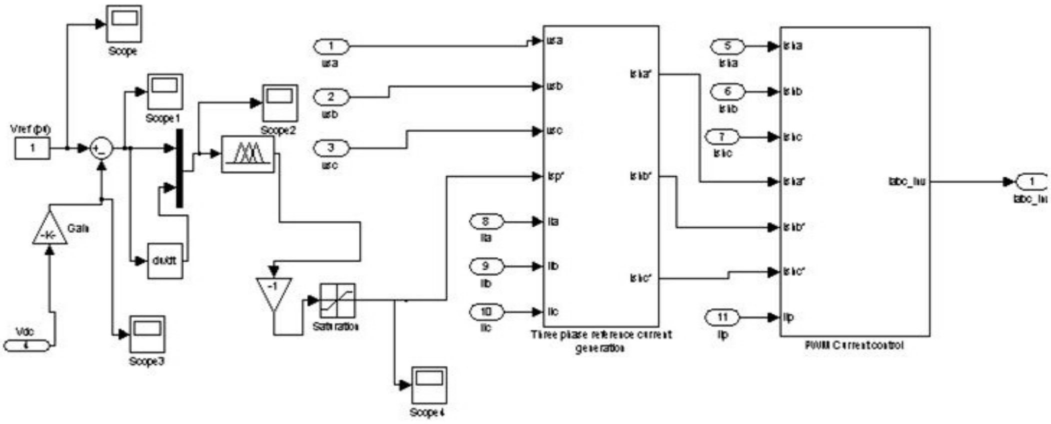


Figure 5: Shunt Control Block for Direct Current Control

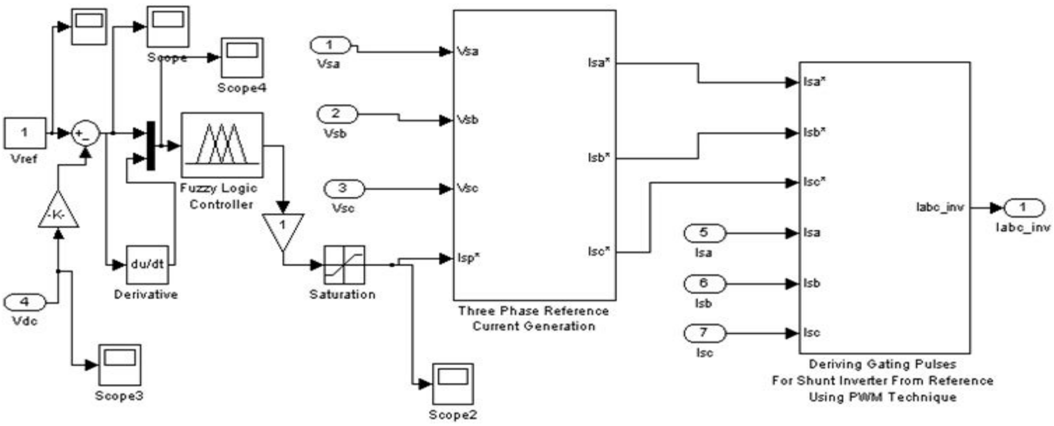


Figure 6: Shunt Control Block for In-direct Current Control

### Series Control Simulation Diagram

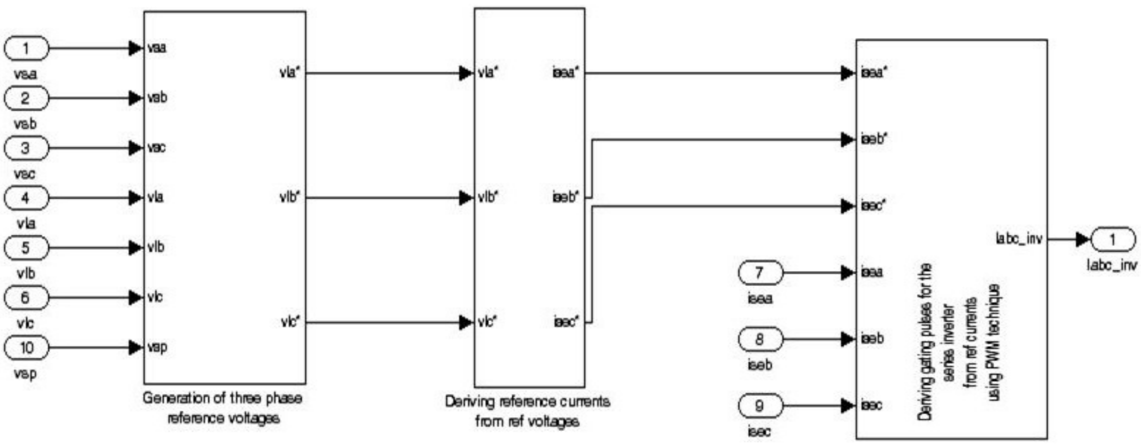


Figure 7: Series Control Block (Sub-system)

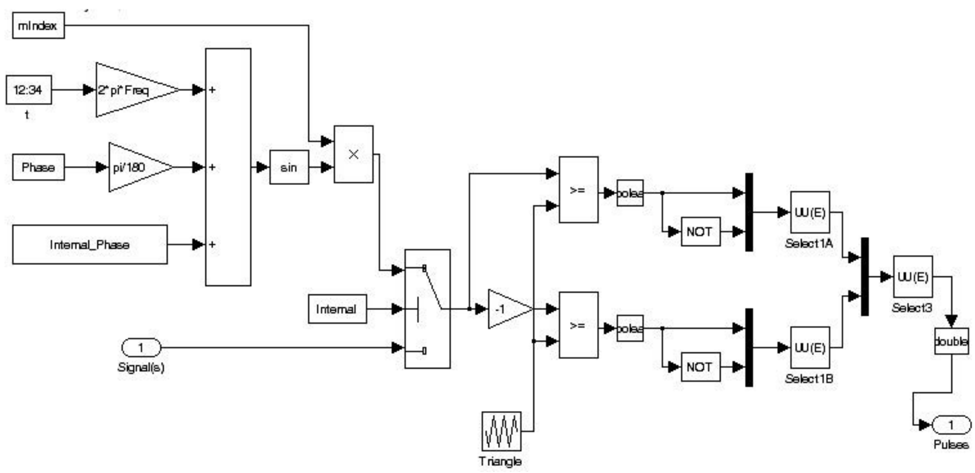


**Figure 8: PWM Generator Generating Gate Pulses**

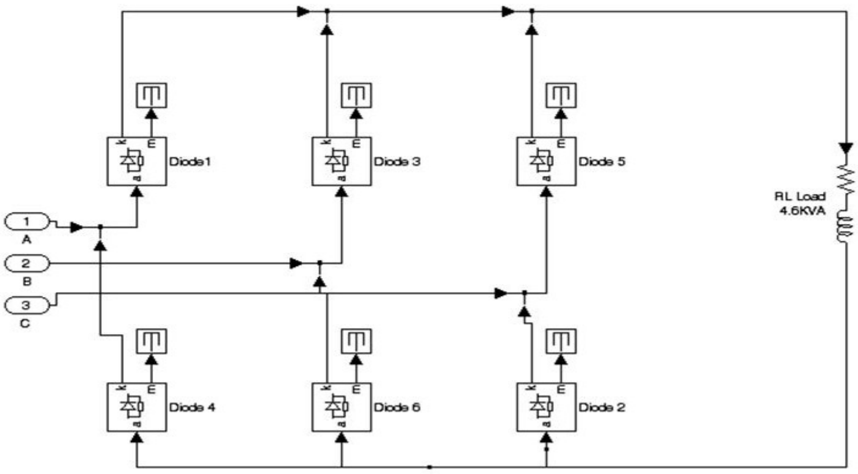


**Figure 9: Non-Linear Load (Diode Rectifier Feeding RL-load)**

**Simulation Results**

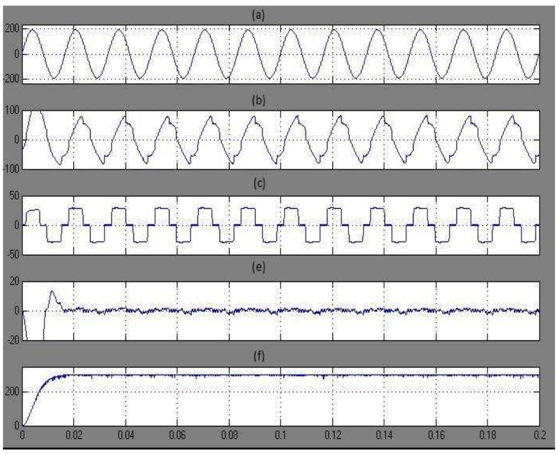


**Figure 10:** Simulation results of ideal three-phase supply feeding Non-linear Load (Diode rectifier feeding R-L load) using Direct Current Control (a) Supply voltage in the A-phase. (b) Supply current in phase-A. (c) Load current in phase-A. (d) Shunt compensating current in phase-A. (e) The dc capacitor voltage. (f) DC link voltage

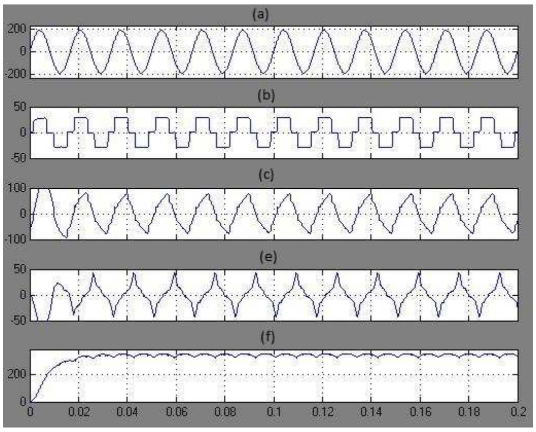


**Figure 11:**Simulation results of ideal three-phase supply feeding Non-linear Load (Diode rectifier feeding R-L load) using In-direct current control (a)Supply voltage in phase-A. (b) Load current in phase-A. (c) Supply current in phase-A (d) Shunt compensating current in phase-A. (e) The dc capacitor voltage(f) DC link voltage

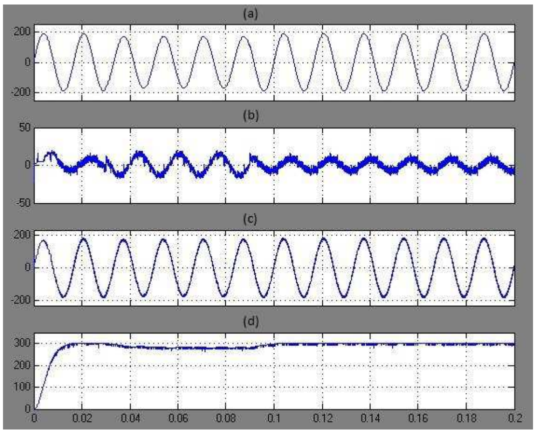


**Figure 12:** Simulation results - Supply voltage with sag of 10% being compensated using series voltage control (a) Supply voltage in the A-phase. (b) Series injected voltage in phase-A. (c) Load voltage in phase-A. (d) The dc capacitor voltage.

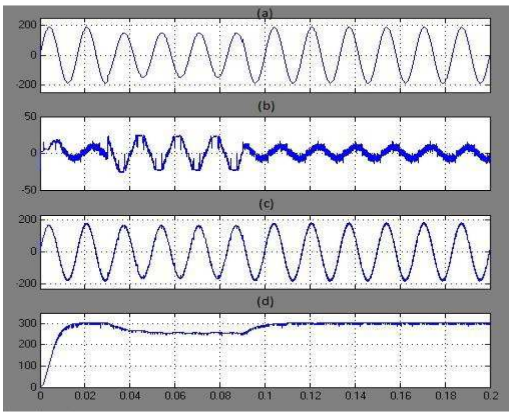


**Figure 13:** Simulation results - Supply voltage with sag of 20% being compensated using series voltage control (a) Supply voltage in the A-phase. (b) Series injected voltage in phase-A. (c) Load voltage in phase-A. (d) The dc capacitor voltage.

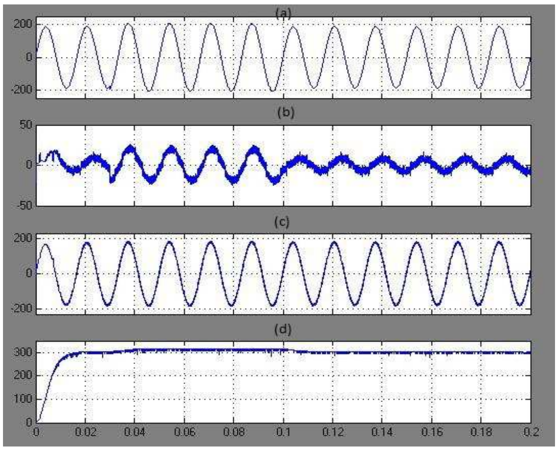


**Figure 14:** Simulation results - Supply voltage with a swell of 10% being compensated using series voltage control (a) Supply voltage in the A-phase. (b) Series injected voltage in phase-A. (c) Load voltage in phase-A. (d) The dc capacitor voltage.

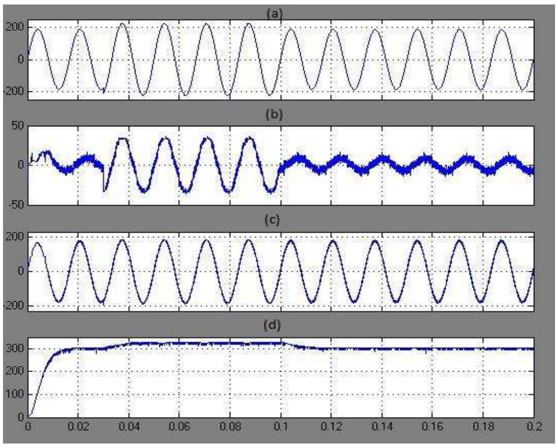


**Figure 15:** Simulation results - Supply voltage with a swell of 20% being compensated using series voltage control (a) Supply voltage in the A-phase. (b) Series injected voltage in phase-A. (c) Load voltage in phase-A. (d) The dc capacitor voltage.

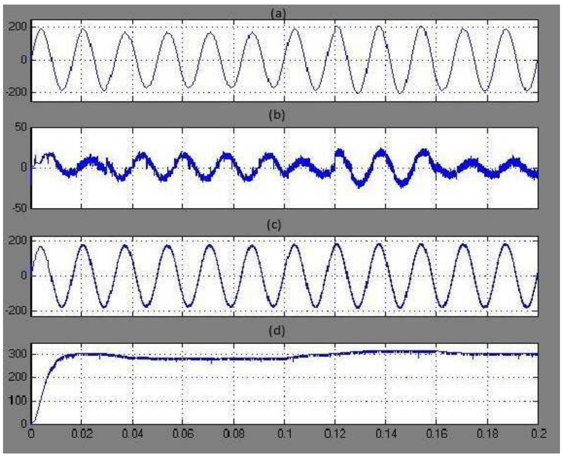


**Figure 16:** Simulation results - Supply voltage with both sag and swell of 10% being compensated using series voltage control (a) Supply voltage in the A-phase. (b) Series injected voltage in phase-A. (c) Load voltage in phase-A. (d)

The dc capacitor voltage.

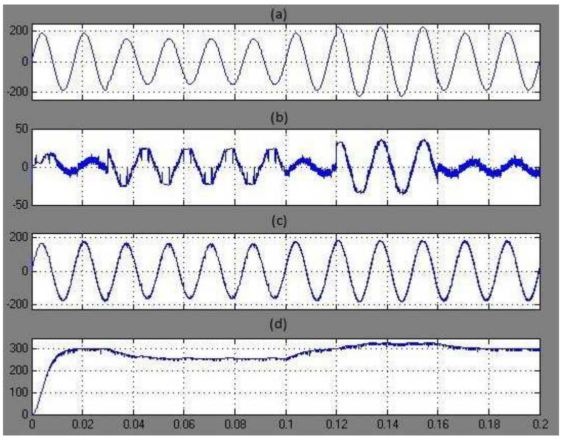


**Figure 17:** Simulation results - Supply voltage with both sag and swell of 20% being compensated using series voltage control (a) Supply voltage in the A-phase. (b)Series injected voltage in phase-A. (c) Load voltage in phase-A. (d) The dc capacitor voltage.

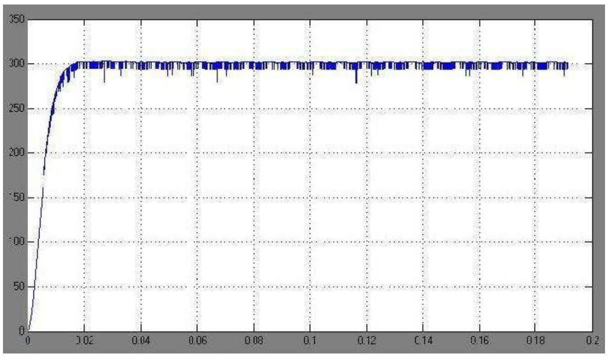

**Figure 18: $V_{dc}$ Using Fuzzy Logic Controller (The DC link Voltage Settled Within 20ms)**

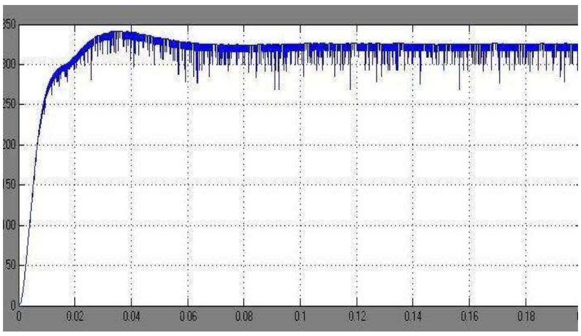

**Figure 18: $V_{dc}$ Using PI Controller (The DC Link Takes more than 20ms)**

## CASE STUDY

For the purpose of analyzing the performance of UPQC designed using the control strategy discussed above, the following case study is considered. A three phase supply of 230v, 60Hz is considered to be feeding a diode rectifier fed RL Load (non-linear load) with a rating of 4.6 KVA. Considering negligible impedance of source and R=0.1Ω & L= 0.2mH. The series and shunt inverter of UPQC are modeled using IGBT bridges/diode bridges.

The shunt inverter parameters are:

$R_{sh}$ = 1 ohm, $L_{sh}$ = 5 mH.

The series inverter parameters are:

$R_{se}$ = 0.2 ohm, $L_{se}$ = 5 mH.

The value of the capacitor providing dc link voltage is 2000μf.

The Values of RL passive filter:

R=1 ohm; L = 8 mH.

## CONCLUSIONS

The closed loop control schemes-Direct and Indirect, for the proposed UPQC have been described. A suitable mathematical model of the UPQC has been developed and simulated results have been shown.

Simulated results shown in Fig. 10 & 11 confirm that there are switching ripples in the supply current when the shunt inverter of UPQC is operated with direct current control technique, while using indirect current technique reduces switching ripple problems to a great extent. Thus simulated results have established that indirect current control technique of the shunt filter offers much better performance and has been found to be promising one towards the compensation of harmonics in the load current. The series filter was tested with sag, swell and combination of both in supply voltage for the values of 10 % and 20% and the voltage at the load was found to be restored close to ideal supply value, and the load voltage harmonics are effectively reduced by using series filter. Thus series filter was found to be effective in mitigating the effect of voltage sag and swell in utility voltage and to maintain load voltage to the desired value. The simulation results above show that the DC link voltage is better recovered in case of Fuzzy logic controller than the conventional PI controller and it involves simple calculations to mitigate the harmonic content. The DC link voltage control using Fuzzy logic controller has better dynamic performance than that of PI controller.

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